Attachment 5

Work Plan

The goal of this work plan is to develop and calibrate a numerical groundwater-flow model of the Six Basins, and use it to predict and evaluate the long-term effects of implementation of the Strategic Plan for the Six Basins. The model will be developed using an industry-standard code (MODFLOW) which will allow for future improvements and the on-going use of the model by the stakeholders to manage the Six Basins.

The work plan to develop, calibrate, and use the model is described below and consists of six tasks:

Task 1 – Develop a Conceptual Model of the Six Basins Area

Task 2 – Build and Calibrate the Numerical Groundwater-Flow Model

Task 3 – Develop and Evaluate the Baseline Alternative

Task 4 – Develop and Evaluate Four Project Alternatives of the Strategic Plan

Task 5 – Prepare Final Report

Task 6 – Project Administration

There are draft and final project deliverables for each task, which will allow for stakeholder input and the evaluation of progress and performance by the stakeholders and the DWR. The entire project will be conducted through a public stakeholder process via the Six Basins Watermaster. Project deliverables will be published on the Watermaster's website (www.6bwm.com), and presentations of the final report will be given at the annual conferences of two major California water associations.

Task 1. Develop a Conceptual Model of the Six Basins Area

The objectives of this task are to collect all the data and information necessary to complete the investigation and develop a conceptual model of the Six Basins in enough detail to build and calibrate the numerical groundwater-flow model.

Task 1.1 Collect, compile, and review all relevant reports, data, and information

Currently, the Six Basins Watermaster is collecting and compiling various data sets and using these data to describe the physical state of the Six Basins in Phase 1 of the Strategic Plan. These data include a significant volume of surface-water and groundwater data, such as precipitation, surface-water discharge, spreading, well locations, well construction, borehole geophysics and lithology, specific capacity, groundwater production, groundwater levels, groundwater quality, and pumping-test data and interpretations in the Six Basins area.

GIS data are also being acquired, including digital air photos, historical land use maps that that indicate water use, the time history of flood control improvements and related operating characteristics as they pertain to diversion and recharge, delineation of sewered areas and septic areas, locations of wastewater treatment plants and method of disposal; location, description and historical operation of surface-water delivery systems used to supply agricultural and urban uses, and other information.

For this work plan, the existing data and information will be reviewed to assess the ability to complete this modeling investigation. There will be data gaps, particularly for data to support the characterization of the hydrologic budget (e.g. areal recharge, mountain-front inflow, etc.). These data gaps will be identified, and missing data, if available, will be collected and compiled into the database. A project GIS will be developed to support the modeling and reporting elements of this work plan.

Task 1.2 Collect and analyze existing models of Six Basins and Chino Basin

The existing finite-element model of the Six Basins prepared by Camp, Dresser, and McKee (CDM, 2006) will be collected and the useful information will be extracted and analyzed. For example, the finite-element model contains a conceptual model that can serve as a starting point and/or a comparison while constructing the new conceptual model.

This work plan proposes to extend the finite-difference grid of the Chino Basin MODFLOW model across the Six Basins. Hence, the Chino Basin model is a major and necessary source of information and will be collected and prepared for use.

Task 1.3 Identify the calibration period

The objective of this task is to select a *calibration period*. All information collected and analyzed over a *historical period* in previous tasks will be analyzed to select the *calibration period*. The term *historical period* as used in this work plan is assumed to be equal to or greater than the *calibration period*. The *calibration period* will be selected as a long-as-possible subset of the *historical period* and will end in 2012. The criteria evaluated to select the *calibration period* will include the length and quality of records for groundwater pumping, groundwater levels, and hydrologic data. The *calibration period* should be as long as practical, and include wet and dry periods and, if possible, a full range of anthropogenic stresses.

Task 1.4 Characterize the hydrogeologic framework and aquifer properties

In this task, the geology and hydrostratigraphy are described and the initial estimates of aquifer properties are developed. First, hydrostratigraphic cross-sections are prepared to depict the hydrostratigraphy of the study area and the geometry of the conceptual model. The types of well data shown on the cross-sections will include borehole lithology and geophysics, perforated intervals, water quality, and production characteristics (*e.g.* specific capacity). Using the cross-sections, the generalized layers of the aquifer system are defined. Barriers to groundwater flow will be shown on the cross-sections. The layer elevations at each well are identified by the hydrogeologist, and are imported to ArcGIS as a point shape file. The bottom of each aquifer layer is hand-contoured on maps and digitized. The digitized contours are used to create raster surfaces in the Geostatistical Analyst extension of ArcGIS. The layers are subtracted from each other to characterize layer thickness to check for interpolation errors.

Next, the borehole lithology data, specific capacity data, and pumping-test data are analyzed to develop initial estimates of aquifer properties by layer. These properties will include hydraulic conductivities (both horizontal and vertical), transmissivity, specific yield, porosity, and storativity. The heterogeneity of the aquifer parameters will assessed based on the thickness percentage of coarse-, mixed-, and fine-grain materials. Geostatistical methods will be used to illustrate the spatial heterogeneity of aquifer properties and identify possible fluvial processes that produced these trends.

Task 1.5 Estimate groundwater production for the calibration period

The objective of this task is to prepare estimates of groundwater production by layer to generate input data for model calibration in Task 2. The groundwater production data collected and compiled in Task 1.1, well perforation data, aquifer layer elevations, and initial estimates of hydraulic conductivity by layer will be used to estimate groundwater production by well and by layer for the *calibration period*.

Task 1.6 Characterize boundary conditions and the hydrologic budget

Sophisticated techniques will be employed to estimate the boundary conditions and the hydrologic budget of the Six Basins. The major boundary conditions include subsurface inflow from the San Gabriel Mountains, subsurface outflow to Chino Basin, and surface outflow from areas of rising groundwater. A model developed by the USGS (RSFLOW) will be used to estimate deep percolation of precipitation in the San Gabriel Mountains and how that groundwater flows into the Six Basins as mountain-front recharge. Estimates from the existing models of the Six Basins and the Chino Basin will be used to characterize the initial estimates of subsurface outflow of groundwater to the Chino Basin and surface-water outflow from rising groundwater.

Another important hydrologic component for the Six Basins is areal recharge from precipitation and applied water when these waters migrate past the root zone, and from stormwater runoff that percolates at spreading grounds and in un-lined stream channels. A sophisticated computer-simulation model of surface water will estimate areal recharge to the groundwater basin on a daily time-step (R4 Model). The R4 Model has been used by the Santa Ana Regional Water Quality Control Board to set its wasteload allocations for wastewater plants that discharge effluent to the Santa Ana River and its tributaries. The R4 model was developed for use in Chino Basin, and has been used to provide recharge estimates for the MODFLOW model over the past 14 years to support recharge master planning efforts and other groundwater basin management programs. The R4 Model includes three modules: Rainfall/Runoff (Runoff Module), Router (Router Module), and Root Zone (Root Zone Module). The R4 Model considers applied water from urban and agricultural land uses, precipitation that falls upon the tributary watersheds, losses to evapotranspiration, runoff, routing of the runoff through flood-control and conservation infrastructure, and losses of surface runoff. The data and information used as input to the R4 Model includes: delineations of the tributary sub-watersheds, historical precipitation data, soil maps, land use maps, channel-lining characteristics, flood-control and water-conservation infrastructure and operations, and evapotranspiration data.

The daily recharge estimates from the R4 and RSFLOW will be summarized and used as input data to the MODFLOW groundwater-flow model to simulate historical conditions for model calibration in Task 2. The R4 and RSFLOW models also will use future planning information to estimate future recharge for model projections in Task 3 and Task 4.

Task 1.7 Describe groundwater flow systems

Groundwater-level time-series charts will be prepared and reviewed for each well in the Six Basins. These time-series charts will describe the fluctuations in groundwater levels across the Six Basins over time. Key periods in time will be identified (*e.g.* periods of high and low groundwater levels) and groundwater-elevation contour maps will be prepared and analyzed to reveal a conceptual understanding of the groundwater flow systems. Of key importance will be the identification of flow gradients within and between aquifers, the effects of barriers to groundwater flow, and the identification of aquifer mergence zones (as indicated by equilibration of heads in the vertical direction). The contour maps and the time-series charts will assist in the characterization of the hydrologic budget (*e.g.* characterization of storage changes) and will be used later in model calibration (e.g. as initial conditions and calibration targets).

Task 1.8 Characterize the initial conditions for the calibration period

The initial conditions are the piezometric heads for each aquifer layer. The initial conditions will be derived from the characterization of the groundwater-flow systems (Task 1.7). The initial condition will be used in Task 2 for steady-state calibration.

Task 1.9 Prepare Task 1 Report -- Conceptual Model Report

The deliverable for this task will be a technical memorandum titled *Task 1 Report – Conceptual Model Report* that will include detailed text, tables and graphics that describe and document the conceptual model. This report will include recommendations for the numerical model design, including the model domain, layering, anticipated range of aquifer and aquitard properties, a detailed description of the hydrology of the Six Basins area, and an initial hydrologic budget for the Six Basins area. A draft report will be distributed to the parties for review and comment. A final report will be prepared that incorporates the comments and suggested revisions of the parties.

Task 2. Build and Calibrate the Numerical Groundwater-Flow Model

The objective of this task is to build and calibrate a groundwater-flow model that reproduces the observed changes in groundwater levels and flows over the *calibration period*. This task will use the conceptual model of the Six Basins to build a 3-dimensional groundwater flow model. Steady-state and transient flow calibrations will be performed. The model must calibrate to a standard that ensures its usefulness as a predictive computer-simulation tool.

Task 2.1 Build numerical model from conceptual model

The objective of this task is to construct an initial working version of the groundwater-flow model for calibration. The model grid from the Chino Basin will be extended across the Six Basins. This expansion of the grid will require some adjustments to the model files for the Chino Basin portion of the model. The conceptual model of the Six Basins that was constructed in Task 1 will be converted into model input files for MODFLOW. The parts of the conceptual model that will be converted includes the ground surface, aquifer geometry, initial aquifer properties and their heterogeneities in space, internal barriers to groundwater flow, initial conditions, and boundary conditions that include deep percolation from precipitation and applied water, storm water recharge, artificial recharge, subsurface inflow and outflow, and groundwater production.

Task 2.2 Perform steady-state calibration of the model

The objective of this task is to run a steady-state calibration of the model to refine the initial estimates of the aquifer properties, the initial conditions, and initial estimates of hydraulic properties of the internal barriers. Calibration targets for the steady-state calibration will be the measured groundwater elevations described in the conceptual model for the beginning of the *calibration period*. The primary metric for the calibration will be the residual differences between observed and simulated groundwater elevations.

Task 2.3 Perform transient calibration of the model

The objective of the transient flow calibration is to adjust the model parameters within a defined range such that the model can reproduce observed trends in groundwater levels. The model will be calibrated to the same time discretization level as the desired predictive simulations (quarterly).

The initial estimates of the aquifer properties and the initial conditions derived during steady-state calibration will be input data for the beginning of the transient calibration. Other input files will include groundwater production and the time-varying boundary conditions and hydrologic fluxes estimated in the conceptual model during the *calibration period*.

The transient calibration targets will consist of time-varying, measured groundwater levels from monitoring and production wells. The criteria for selecting wells will be the desire to have a good spatial coverage of targets across each parameter zone and model layer and the completeness and quality of static groundwater-level measurements at the wells.

An automated parameter estimating approach using PEST will be used with all parameters constrained within a prescribed range of reasonable values as described in the conceptual model. An upper and lower bound for each parameter (as described in the conceptual model) will constrain or bound the value of each parameter. Specifically, the code Parallel PEST will be used to allow multiple simulations to run and maximize efficiency. The objective function used in PEST is the sum of the squared weighted residuals; the residual being the difference between an observed and model estimated groundwater level. PEST minimizes the objective function by iteratively updating the model parameters. The value of the objective function decreases iteratively with the progress of calibration. The simulation is repeated with updated parameters using a minimization algorithm. A system of 24 computers will be configured to operate in parallel, which will allow for the completion of steady-state calibration and transient calibration in a fraction of the time used by a single processor.

In each calibration iteration, a series of sensitivity analysis will be conducted to determine which parameters should be adjusted in subsequent optimization iteration. After each iteration, residual analyses and parameter-correlation-matrix analyses will be conducted to provide some measure of the overall goodness-of-fit, and to identify potential systematic errors, trends in the model, or outliers in the data. Note that a good match between simulated and measured water levels does not necessarily mean that the estimates are reasonable. They may be highly uncertain due to high parameter correlation, which is usually an indication of over-parameterization.

The transient calibration will be described by both quantitative and qualitative means via the following exhibits:

- *Scatter plots*. For steady-state and transient calibration, observed versus simulated scatter plots will be prepared. For transient calibration, residuals for all stress periods will be prepared. Plots will be color coded by well to show calibration performance at individual wells.

- *Residual distribution charts*. Charts will be prepared showing the residual frequency distribution, mean of residuals, and statistics of residuals. These charts reveal potential trends in the residuals, indicating if there is a systematic error in the model or the data.

Note that if the statistics of the residuals significantly deviate from normal, the estimates are likely to be biased and the model will need to be modified.

- *Contour maps*. Maps showing the simulated and observed groundwater elevation contours, both steady-state and at selected times during the transient calibration period, will be prepared for visual comparison.
- *Hydrographs*. Time-series charts of observed and simulated groundwater elevations for selected wells will be prepared. In some cases, multiple aquifer (layer) trends will be shown on the same graph to illustrate trends between aquifers.
- *Hydrologic budget*. The final calibration will include a detailed hydrologic budget analysis.

Task 2.4 Prepare Task 2 Report -- Build and Calibrate Model

The deliverable for this task will be a technical memorandum titled *Task 2 Report -- Build and Calibrate Model* that describes and documents the numerical model and its calibration. A draft memorandum will be distributed to the parties for review and comment. A final memorandum will be prepared that incorporates the comments and suggested revisions of the parties.

Task 3. Develop and Evaluate the Baseline Alternative

The objectives of this task are to develop a Baseline Alternative that represents the uncoordinated actions of the pumpers without a Strategic Plan, and evaluate the Baseline Alternative over a 60-year future period.

Task 3.1 Establish the planning period

For this proposal, the *planning period* is assumed to be 60 years (2013-2072). The *planning period* needs extend beyond the ultimate plans of the local planning agencies, and be long enough to demonstrate the long-term effects project alternatives on the groundwater resources of the Six Basins and the Chino Basin. The planning information collected and compiled in Task 1 and the model calibration results will be analyzed to select the appropriate *planning period.*

Task 3.2 Estimate the hydrologic budget of the planning period

The same techniques used to estimate the boundary conditions and hydrologic budget for the *calibration period* in Task 2 will be used to estimate the boundary conditions and hydrologic budget for the *planning period.* In this effort, input data for the surface-water models that estimate the mountain-front inflows and areal recharge will use future estimates of land use and a long-term historical precipitation record. These estimates will be summarized and used as input data to the MODFLOW groundwater-flow model to simulate the Baseline Alternative.

Task 3.3 Describe the Baseline Alternative

The current planning documents of the water purveyors will be collected and analyzed (*e.g.* Urban Water Management Plans). The Baseline Alternative will be a description of the future uncoordinated plans of the pumpers in the Six Basins (i.e. pumping in the absence of a Strategic Plan). Tables and figures will be prepared to describe the Baseline Alternative. The water purveyors will have the opportunity to review and comment on the assumptions of the Baseline Alternative prior to simulation.

Task 3.4 Evaluate the Baseline Alternative

The tables and figures that describe the Baseline Alternative will be converted to input files for MODFLOW. The Baseline Alternative will be simulated and the results will be analyzed in tables, charts, and maps. Various metrics will be used to evaluate the Baseline Alternative which will include at a minimum: changes in groundwater levels (average groundwater-level change over time by model layer by water management agency; time histories at key wells; differences in pumping energy in each water management agency service area); changes in surface water discharge in areas where surface and groundwater interact; and changes in subsurface inflow and outflow at boundaries.

Task 3.5 Prepare Task 3 Report -- Evaluation of the Baseline Alternative

The deliverable for this task will be a technical memorandum titled *Task 3 Report -- Evaluation of the Baseline Alternative* that describes and documents the results of the simulation of the Baseline Alternative. A draft memorandum will be distributed to the parties for review and comment. A final memorandum will be prepared that incorporates the comments and suggested revisions of the parties.

Task 4. Develop and Evaluate Four Project Alternatives of the Strategic Plan

The objectives of this task are to develop four Project Alternatives that represent the coordinated actions of the pumpers with a Strategic Plan, simulate each Project Alternative over the *planning period*, and compare the results of each simulation to the Baseline Alternative and to each other.

Task 4.1 Describe four project alternatives of the Strategic Plan

Various project alternatives will be developed during Phase 2 of the Strategic Plan process. These project alternatives are currently undefined, but may include new groundwater production patterns to mitigate rising groundwater, pump-and-treat facilities and strategies to put poor-quality groundwater to beneficial use, and/or expanded storage and recovery programs, among others. Tables and figures will be prepared to describe the project alternatives. The stakeholders will be developing these project alternatives during Phase 2 of the Strategic Plan process, and will have the opportunity to review and comment on the assumptions of the project alternatives prior to simulation.

Task 4.2 Evaluate the four project alternatives of the Strategic Plan

The tables and figures that describe the project alternatives will be converted to input files for MODFLOW. The project alternatives will be simulated and the results will be analyzed in tables, charts, and maps. The same metrics used to evaluate the Baseline Alternative will be used to comparatively evaluate the project alternatives to the Baseline Alternative and to each other.

Task 4.3 Prepare Task 4 Report -- Evaluation of the Project Alternatives of the Strategic Plan

The deliverable for this task will be a technical memorandum titled *Task 4 Report -- Evaluation of the Project Alternatives of the Strategic Plan* that describes and documents the results of the simulation of the project alternatives and the comparison to the Baseline Alternative and to each other. A draft memorandum will be distributed to the parties for review and comment. A final memorandum will be prepared that incorporates the comments and suggested revisions of the parties.

Task 5. Prepare Final Report

Task 5.1 Prepare model documentation

Model documentation will include preparation of executable files for the groundwater flow model, all the input and output files from the calibration simulations, and all the input and output files for the planning simulations. The model documentation will be included on CD within the final report with a readme file that describes the included files and how to use them.

Task 5.2 Prepare draft and final reports

The technical memoranda prepared in the first four tasks will be compiled into a final report. The final report will include conclusions and recommendations for the scope and timing of implementation of the Strategic Plan. It will also include descriptions of the short-term and long-term effects of the Strategic Plan at individual wells, on the services areas of the individual water purveyors, on the individual sub-basins of the Six Basins, on the collective Six Basins, and on the Chino Basin.

A draft final report will be distributed to the parties for review and comment. A final report will be prepared that incorporates the comments and suggested revisions of the parties.

Task 6. Project Administration

The objectives of this task are to execute the project within the stakeholder process, conduct public outreach, and prepare invoices and progress reports for the DWR pursuant to the requirements of the LGA grant agreement.

Task 6.1 Prepare for and attend 12 monthly workshops

The stakeholder process in the Six Basins includes monthly meetings of the Board of Directors and the Advisory Committee on alternating months. Since the development of the Strategic Plan commenced in 2012, the stakeholders have been conducting Strategic Plan workshops following the Board and Advisory Committee meetings. The technical consultant executing the modeling work will prepare for and attend 12 Strategic Plan workshops to describe progress and results and receive feedback from the stakeholders.

Task 6.2 Technical Review Committee

The project will have a technical review committee (TRC) that will meet at key milestones during the project, for example at project kickoff, development of the conceptual model, steady-state calibration, *etc*. The TRC will be comprised of the project team's senior groundwater modeling expert, a representative from the stakeholder group, and an independent consultant who is recognized as a leading expert in regional groundwater simulation modeling. The expert will be hired as a sub-consultant.

Task 6.3 Prepare for and attend two association meetings to describe project results

The technical consultant that executes the modeling work will present the final report at an annual meeting of the Association of California Water Agencies and at a technical meeting of the Groundwater Resources Association of California. The PowerPoint presentations from these meetings will be submitted with the final report to the DWR.

Task 6.4 Prepare quarterly invoices and progress reports and the final report for the DWR

The technical consultant that executes the modeling work will prepare quarterly invoices and progress reports and the DWR final report pursuant to the requirements of the LGA grant agreement.